Subsoiling for Nitrogen Applications to Corn Grown in a Conservation Tillage System[1]

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ABSTRACT

Subsoiling not only improves root penetration and water infiltration but may also provide an efficient means of applying N fertilizer. Field studies were conducted 2 yr on a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) and 1 yr on a Dothan fine-sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudults) to determine the effect of N source and application method, subsoiling placement, and time of subsoiling and N application on the efficiency of N applied to no-till corn (*Zea mays* L.). Urea and NH_4NO_3 (157 kg ha^{-1}) were applied (i) surface-banded at planting, (ii) in the in-row subsoil track at planting, (iii) surface-banded 5 weeks after planting, or (iv) interrow with subsoilers 5 weeks after planting. Nitrification inhibitors, dicyandiamide (cyanoguanidine) (DCD) and ethylene dibromide (1-2-dibromoethane) (EDB), were also used with urea applied in subsoil tracks. Neither inhibitor affected grain yields. Applying N in the subsoil track proved an effective application method. Generally, highest yields (8204 to 9486 kg ha^{-1}) were obtained by applying N 5 weeks after planting with in-row subsoiling. Results indicate no benefit to subsoiling interrow if in-row subsoiling was done at planting; however, if corn was planted without in-row subsoiling, subsoiling interrow 5 weeks later improved yields. Interrow subsoiling may be a practical alternate management tool, especially when used to apply sidedressed N, for growers in years when subsoiling at planting is not feasible.

***Additional index words:* *Zea mays* L., Nitrification inhibitor, Ethylene dibromide, Dicyandiamide, Ammonium nitrate, Urea, Fertilizer placement.**

INCREASED N immobilization (Rice and Smith, 1984; Kitur et al. 1984), losses of nitrate via leaching (McMahon and Thomas, 1976; Thomas et al. 1981), and denitrification (Rice and Smith, 1982; Aulakh et al. 1984) are factors that can lower efficiency of applied N fertilizer, regardless of source, in conservation-tillage systems. However, the high urease activity associated with organic matter in surface mulches of conservation-tillage systems (Klein and Koths, 1980) can make surface applications of urea in these systems particularly ineffective. Bandel et al. (1980), in a 3-yr study conducted on three soils, reported higher yields with surface-applied ammonium nitrate than with surface-applied urea or urea-containing nitrogen solution. Exceptions occurred in years and locations when there was no yield response to applied N or when unfavorable environmental conditions caused extremely low yields. The authors stressed the need for developing field equipment for subsurface application of urea fertilizers. Touchton and Hargrove (1982) compared the efficiency of urea-ammonium nitrate solution (UAN), prilled ammonium nitrate, and prilled urea applications to no-till corn (*Zea mays* L.) grown on a Cecil sandy loam (Typic Hapludults). Based on grain yield and N recovered in grain, the order of efficiency of the N sources was urea $<$ UAN $\leqslant$ ammonium nitrate. Fox and Hoffman (1981) applied five rates of broadcast, unincorporated N as ammonium nitrate, urea, UAN solution, or ammonium sulfate to no-till corn grown on a Murrill silt loam (Typic Hapludults). In 2 of 4 yr, either urea or UAN, or both, resulted in lower yields and N uptake than the non-urea sources at N rates of 101 and 202 kg ha^{-1}.

Root-restricting tillage pans are readily formed in many of the sandy soils of the Southern Coastal Plain (Reicosky et al., 1977; Kashirad et al., 1967). The use of no-till planters equipped with in-row subsoilers, commonly referred to as strip tillage, has proved an effective method for enabling crop roots to access subsoil water and nutrients (Trouse, 1983; Weatherly and Dane, 1979). Since incorporation of urea fertilizers can enhance their effectiveness in conservation-tillage systems (Bandel et al., 1984; Mengel et al., 1982), deep placement of urea directly behind subsoil shanks should be a practical method of improving fertilizer N efficiency. One potential problem, however, is that large volumes of irrigation and rainwater can rapidly penetrate subsoil channels. Consequently, deep placement of N fertilizers in subsoil channels, especially when applied at planting, might result in excessive losses of N via leaching.

The use of nitrification inhibitors with subsoil-placed N might lessen the potential for leaching losses. Two chemicals, dicyandiamide (cyanoguanidine) (DCD) and ethylene dibromide (1,2-dibromoethane) (EDB), are feasible nitrification inhibitors to use with subsoil-placed solid urea. Urea can be effectively mixed with DCD (Reider and Michaud, 1980) and urea containing DCD is currently marketed by companies in Japan and West Germany (Slangen and Kerkoff, 1984). The recently banned soil fumigant, EDB, can be easily injected in conjunction with solid urea dropped behind subsoilers. Although it is no longer marketed as a soil fumigant, EDB is an effective nitrification inhibitor (Ferguson and Green, 1979).

Increased water infiltration and reduced surface runoff are important aspects of strip tillage. As corn plants develop, however, a large portion of the rainfall or irrigation water that strikes the canopy is shed away from the row toward the row middle. Interrow subsoiling might provide a means for reducing runoff and increasing infiltration of water shed toward row middles. Also, delaying bulk N applications 4 to 6 weeks after planting, to coincide with the crop's potential for utilization, can increase N effectiveness (Jung et al., 1972; Russelle et al., 1983). Coinciding N application with interrow subsoiling 4 to 6 weeks after planting may thus be a practical production practice.

The objectives of this study were to (i) determine the effect of planting-tillage method, subsoiling placement, and time of subsoiling on growth and yield of corn grown in a conservation-tillage system; (ii) evaluate the efficiency of deep-placed urea to corn grown in a conservation-tillage system as affected by time of application and subsoiling placement; and (iii) determine if nitrification inhibitors would improve the efficiency of deep-placed urea.

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Table 1. Planting variables and cultural practices used in this study.

Year	Soil	Winter cover	Planting date	Seeding rate	Uniform plant population	Row width	Brand–variety
				ha⁻¹		m	
1983	Norfolk	Soybean [*Glycine max* (L.) Merr.] stubble and winter weeds	5 April	128 000	49 000	0.68	Ring Around 1502
1984	Norfolk	Rye (*Secale cereale* L.)	7 April	99 000	59 000	0.68	Ring Around 1502
1984	Dothan	Rye (*Secale cereale* L.)	26 March	99 000	59 000	Twin 0.18-m rows on 0.90-m centers	Dekalb–T1230

Table 2. Treatment variable combinations used in this study.

Treatment	Subsoiling†	N source	Application method
		N applied at planting	
1	in-row	NH_4NO_3	surface band
2	in-row	urea	surface band
3	in-row	NH_4NO_3	subsoil channel
4	in-row	urea	subsoil channel
5	in-row	urea + DCD	subsoil channel
6	in-row	urea + EDB	subsoil channel
7	none	NH_4NO_3	surface band
8	none	urea	surface band
		N applied 5 weeks after planting	
9	in-row + interrow	NH_4NO_3	surface band
10	in-row + interrow	urea	surface band
11	in-row + interrow	NH_4NO_3	subsoil channel
12	in-row + interrow	urea	subsoil channel
13	in-row + interrow	urea + DCD	subsoil channel
14	in-row + interrow	urea + EDB	subsoil channel
15	in-row	NH_4NO_3	surface band
16	in-row	urea	surface band
17	interrow	NH_4NO_3	surface band
18	interrow	urea	surface band
19	interrow	NH_4NO_3	subsoil channel
20	interrow	urea	subsoil channel
21	interrow	urea + DCD	subsoil channel
22	interrow	urea + EDB	subsoil channel
23	none	NH_4NO_3	surface band
24	none	urea	surface band

† In-row subsoiled at planting; interrow subsoiled 5 weeks after planting.

MATERIALS AND METHODS

Subsoiling × fertilizer management practices were evaluated for 2 yr (1983 and 1984) on a Norfolk sandy loam (fine-loamy, siliceous, thermic Typic Paleudults) in central Alabama, and for 1 yr on a Dothan fine-sandy loam (fine-loamy, siliceous, thermic Plinthic Paleudults) in southern Alabama. In central Alabama, the experimental location was different but adjacent in 1983 and 1984. Soils at both locations had a 0.04- to 0.10-m thick tillage or traffic pan located 0.20 to 0.35 m below the surface at the transition of Ap to Bt horizons. The Bt horizons extend to depths exceeding 1.65 m on both soils. The organic matter content and cation exchange capacities for both soils were approximately 10 g kg^{-1} and 4 cmol (+) kg^{-1}, respectively. Initial soil pH of the Norfolk soil sites in 1983 and 1984 was 5.9, and Mehlich I extractable P, K, Ca, and Mg (Hue and Evans, 1979) averaged 160, 150, 1300, and 140 kg ha^{-1}, respectively, for the Norfolk soil in 1983; and 140, 140, 960, and 100 kg ha^{-1} in 1984. In February of 1984, 2800 kg ha^{-1} dolomitic limestone was applied to the Norfolk soil. The pH of the Dothan soil was 6.4, and Mehlich I extractable P, K, Ca, and Mg averaged 90, 110, 760, and 160 kg ha^{-1}, respectively. Soil test ratings for P and K for all tests were "high" (Cope et al., 1980); consequently the only P and K applied was as a starter fertilizer.

On the Norfolk soil, corn was planted and appropriate treatments subsoiled (0.35- to 0.40-m depth) with a Cole[3] no-till planter. On the Dothan soil, the Cole implement was used for subsoiling, followed by seeding of twin 0.18-m rows on either side of the subsoil channel with a John Deere Flex-71[3] planter. Six-row plots, 9.1 m long, were planted into a winter cover crop in all tests. Planting dates and other cultural practices are listed in Table 1.

The experimental design was a split plot in a randomized complete block arrangement with three replications. Main plots (time of N application and planting-tillage method) included (i) N applied at planting, (ii) sidedressed N applied 5 weeks after planting to no-till plots that were in-row subsoiled at planting, and (iii) sidedressed N applied 5 weeks after planting to no-till plots planted without in-row subsoiling. Subplots (N source and method of application) included: (i) subsoiled, NH_4NO_3 applied as surface band; (ii) subsoiled, urea applied as surface band; (iii) subsoiled, NH_4NO_3 applied in subsoil track; (iv) subsoiled, urea applied in subsoil track; (v) subsoiled, urea + DCD applied in subsoil track; (vi) subsoiled, urea + EDB applied in subsoil track; (vii) not subsoiled, surface-banded NH_4NO_3; and (viii) not subsoiled, surface-banded urea. Treatment variable combinations are listed in Table 2. The N rate in all treatments was 157 kg ha^{-1} in addition to 22 kg ha^{-1} applied as a starter. Surface N application treatments were banded approximately 0.10 m from the row. Interrow subsoiling was used to apply N 5 weeks after planting in treatments where N was applied in the subsoil channel. The urea + DCD treatment contained 10% of the N as DCD–N and EDB was applied at 18.7 kg ha^{-1} a.i. immediately behind the subsoiler shank.

Starter fertilizers, which consisted of N, P, K, and S, were applied each year at rates of 22, 10, 18, and 25 kg ha^{-1}, respectively. In 1984 Zn and B were also included at rates of 0.7 and 0.2 kg ha^{-1}, respectively. Starter fertilizers were applied in the subsoil track (0.35- to 0.40-m depth) for treatments subsoiled at planting (treatments 1–6 and 9–16), and in a band 70 mm to the side of the row, and incorporated 70 mm deep in treatments not subsoiled at planting (treatments 7, 8, and 17–24).

Plants were thinned 3 weeks after planting to a uniform population (Table 1). In all tests, the winter cover crop (Table 1) was killed with an application of 0.56 kg ha^{-1} paraquat (1,1′-dimethyl-4,4′-bipyridinium ion). Weeds were effectively controlled with a tank mix of 1.68 kg ha^{-1} atrazine [6-chloro-*N*-ethyl-*N*′-(1-methylethyl)-1,3,5-triazine-2,4-diamine] and 1.68 kg ha^{-1} metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl) acetamide], applied 21 to 27 days after planting. All tests were irrigated and irrigation was scheduled with tensiometers when soil water potential at a 0.15-m depth was < -35 kPa. An irrigation system breakdown prevented irrigation for 47 days following emergence in 1983 on the Norfolk soil.

Plant heights were recorded 52 days after planting in 1983 and 45 days after planting in 1984. In 1984, 45 days after planting, whole plant samples were taken from a 1-m section of row for plant dry weight and N determinations. During early silking, earleaf samples were taken for N determinations. At physiological maturity, the two middle rows of each plot were harvested for grain yield determinations (corrected to 155 g kg^{-1} moisture content), and subsamples of grain were taken for N determinations. Nitrogen concentratons were determined by Kjeldahl procedures in 1983 and with a LECO CHN-600[3] carbon-hydrogen-nitrogen analyzer in 1984. Soil samples were taken at 3, 6, and 9 weeks after N application in 1983 and 2, 4, 6, and 8 weeks after N application in 1984 for inorganic N (NH_4^+ and NO_3^-) determinations (Bremner, 1965). Six cores per plot, 0.50 m deep, were taken from the zone of N application, i.e., either within the subsoil channel or 0.10 m from the row.

Data were subjected to analyses of variance (ANOVA) for a split-plot design. Fishers' protected least significant difference (LSD), $P \leq 0.10$, and single degree of freedom comparisons were used for mean separation of preplanned comparisons. Treatments 1 through 8 were compared to treatments 9 through 24 to evaluate effects of N application time. Comparisons of subsoiling treatments were made within treatments where N was applied 5 weeks after planting as surface-band applications of NH_4NO_3 and urea (treatments 9, 10; 15, 16; 17, 18; and 23, 24).

RESULTS AND DISCUSSION

Soil Inorganic N Analyses

Generally, soil inorganic N (NH_4^+–N + NO_3^-–N) concentrations dropped to the level of that found in control plots within 6 to 8 weeks after N application (Table 3). With the exception of the Dothan soil, in 1984, the rate of depletion of inorganic N was greater when application of N fertilizer was delayed until 5 weeks after planting. This indicates that larger plants with more extensive root systems were better able to utilize N fertilizer applied 5 weeks after planting. Higher concentrations of inorganic N in treatments where N was applied in the subsoil channel were probably the result of less dispersion of fertilizer N in these treatments as compared to treatments where N was applied as a surface band (Table 4). Soil NH_4^+–N concentrations were not affected by either DCD or EDB in 1983 or 1984 on the Norfolk soil. In 1984 on the Dothan soil, however, soil NH_4^+–N concentrations from the 0- to 0.50-m depth indicate that both DCD and EDB effectively retarded nitrification of urea placed in the subsoil channel for up to 6 weeks after application (Table 5).

Plant Growth and N Concentrations

Time of N application and placement of starter fertilizer affected early season plant heights and dry weights (Table 6). In 1983, on the Norfolk soil, early season growth was retarded by low temperatures. The mean temperature for the 14-day period following emergence was 5.6° C below the 30-yr norm of 11.3° C. Generally, applying N at planting resulted in the best early season growth. Poorest early season growth occurred in treatments planted with in-row subsoiling where N application was delayed until 5 weeks after planting (treatments 9–16). In these treatments, the starter fertilizer was placed in the subsoil channel, as opposed to the 70 by 70-mm band application made to treatments planted without in-row subsoiling. Occasional problems with availability of deep-placed starters have been reported (Touchton, 1985). Evidently, the corn roots reached and assimilated the starter fertilizer applied in the 70 by 70-mm shallow band much more rapidly than the starter placed deeper in the subsoil channel.

[3] Mention of a trademark name or a proprietary product does not constitute a guarantee or warranty of the product by the U. S. Department of Agriculture or the Alabama Agric. Exp. Stn. and does not imply its approval to the exclusion of other products that may also be suitable.

Table 3. Inorganic N (NH_4^+-N + NO_3^--N) in 0- to 0.50-m depth of soil as affected by time of N application/planting-tillage-method treatments.

Soil, year	Time after application	N at planting	N at 5 weeks, planted without in-row subsoiling	N at 5 weeks, planted with in-row subsoiling
	weeks	Inorganic N, mg kg^{-1}		
Norfolk, 1983	3	49	68	69
	6	50	28	24
	9	40	18	18
$LSD_{0.10}$ for any 2 values = 8.1				
Starter only check† = 31				
Norfolk, 1984	2	74	38	41
	4	39	30	46
	6	28	15	6
	8	9	9	8
$LSD_{0.10}$ for any 2 values = 11.0				
No-N check‡ = 9				
Dothan, 1984	2	49	30	45
	4	28	49	51
	6	29	18	19
	8	9	27	23
$LSD_{0.10}$ for any 2 values = 14.6				
No-N check‡ = 23				

† Check value is from samples taken 3 weeks after planting from plots receiving 22 kg N ha^{-1} in starter fertilizer.
‡ Check values are from samples taken 2 weeks after planting from border plots receiving no fertilizer N.

Table 4. Inorganic N (NH_4^+-N + NO_3^--N) in 0- to 0.50-m depth of soil as affected by N source/application-method treatments.

Treatment	Norfolk, 1983	Norfolk, 1984	Dothan, 1984
	Inorganic N, mg kg^{-1}†		
Not subsoiled, surface NH_4NO_3	37	20	23
Not subsoiled, surface urea	32	19	17
Subsoiled, NH_4NO_3 in track	43	33	25
Subsoiled, surface NH_4NO_3	29	21	24
Subsoiled, surface urea	32	19	24
Subsoiled, urea in track	53	35	41
Subsoiled, urea + DCD in track	41	51	34
Subsoiled, urea + EDB in track	57	53	39
$LSD_{0.10}$	7.1	8.4	6.3

† Values averaged across time of N application/planting-tillage-method treatments and time of sampling.

Table 5. Soil NH_4^+-N concentrations (0- to 0.50-m depth) in 1984 on the Dothan soil as affected by nitrification inhibitors and time of sampling.

Treatment†	2	4	6	8
	NH_4^+-N, mg kg^{-1}			
Urea	41	30	15	10
Urea + DCD	50	52	31	25
Urea + EDB	72	48	34	20
$LSD_{0.10}$ within columns = 15.5				

† All treatments were placed in subsoil channel.

Table 6. Effect of time of N application/planting-tillage-method treatments on early-season plant heights and dry weights.

Treatment	Soil and year		
	Norfolk, 1983	Norfolk, 1984	Dothan, 1984
	Plant height, m†		
N at planting	0.340	0.444	0.424
N at 5 weeks, planted without in-row subsoiling	0.262	0.418	0.414
N at 5 weeks, planted‡ with in-row subsoiling	0.165	0.403	0.353
$LSD_{0.10}$	0.1223	0.0725 NS	0.0337
	Dry wt, g m^{-1} row†		
N at planting	--§	54.9	34.3
N at 5 weeks, planted without in-row subsoiling	--	36.3	25.8
N at 5 weeks, planted‡ with in-row subsoiling	--	35.9	18.5
$LSD_{0.10}$		10.04	6.43

† Data recorded 52 and 45 days after planting in 1983 and 1984, respectively.
‡ Starter fertilizer applied in subsoil channel as opposed to 70 by 70-mm band.
§ Data not recorded in 1983.

Whole plant samples for N analysis were not taken in 1983 because of reduced growth from low temperatures following planting. In 1984, on both soils, whole plant N concentrations 45 days after planting were higher in treatments where N was applied at planting compared to treatments where N was applied 5 weeks after planting (28.3 vs. 22.8 g kg^{-1} average, $P \leq 0.005$, for the Norfolk soil, and 32.4 vs. 29.4 g kg^{-1} average, $P \leq 0.009$, for the Dothan soil).

At anthesis, earleaf N concentrations were not affected by treatments on the Dothan soil (Table 7). In 1983, on the Norfolk soil, time of N application/planting-tillage-method treatments affected earleaf N concentrations. Applying N 5 weeks after planting to plots that had been planted without in-row subsoiling (treatments 17–24) resulted in the highest earleaf N concentration (19.7 g kg^{-1}). Earleaf N concentrations of plots receiving N at planting (treatments 1–8) or in plots receiving N 5 weeks after planting that had been planted with in-row subsoiling (treatments 9–16) were equivalent (17.6 g kg^{-1} average). The increased earleaf N concentration in the nonsubsoiled-at-planting treatments where N was applied 5 weeks after planting was likely due to a concentration effect. By anthesis, differences in plant growth caused by starter availability within treatments receiving N 5 weeks after planting (Table 6) were no longer evident, and plants in treatments planted without in-row subsoiling were visibly smaller than those in treatments planted with in-row subsoiling.

In 1984, on the Norfolk soil, N source/application-method treatments affected earleaf N concentrations (Table 7). Applying N, regardless of source, in the subsoil channel resulted in the highest earleaf N concentrations. Surface applications of urea were particularly ineffective. The February application of dolomitic limestone to the soil surface, which was not incorporated, probably resulted in increased losses of urea via ammonia volatilization in this year on the Norfolk soil.

Grain Yields and N Concentrations

In 1983, on the Norfolk soil, treatment effects on grain yield were amplified by low rainfall (30 mm total) and lack of irrigation for 47 days following emergence. Both time of N application/planting tillage-method treatments and N source/application-method treatments affected grains yields; however, there was no interaction between these treatments (Table 7). Highest yields, pooled across N source and application methods, were obtained by applying N 5 weeks after planting to treatments that were in-row subsoiled at

Table 7. Grain yield, earleaf N concentrations, and grain N concentrations by location and year, as affected by time of N application/planting-tillage-method treatments and N source/application-method treatments.

Treatment	Soil and year								
	Norfolk, 1983			Norfolk, 1984			Dothan, 1984		
	Grain yield	Earleaf N conc.	Grain N conc.	Grain yield	Earleaf N conc.	Grain N conc.	Grain yield	Earleaf N conc.	Grain N conc.
	kg ha^{-1}	g kg^{-1} dry wt		kg ha^{-1}	g kg^{-1} dry wt		kg ha^{-1}	g kg^{-1} dry wt	
	Time of N/planting-tillage method								
N at planting	6390	17.7	18.3	8490	24.2	12.2	8650	30.3	13.5
N at 5 weeks, planted without in-row subsoiling	6520	19.7	18.1	8900	25.8	12.3	9090	34.8	14.4
N at 5 weeks, planted with in-row subsoiling	8200	17.5	18.4	8650	26.0	12.0	9490	35.2	13.7
$LSD_{0.10}$	1355	1.72	NS	NS	NS	NS	575	NS	NS
CV (%)	34.8	14.4	16.1	7.7	13.2	24.7	10.1	20.1	9.4
	N source/application method								
Not subsoiled, surface NH_4NO_3	7030	18.4	18.0	8550	25.1	12.7	8840	33.3	14.0
Not subsoiled, surface urea	6860	19.6	18.3	7830	23.3	10.9	8510	34.8	13.7
Subsoiled, NH_4NO_3 in track	6450	16.5	17.8	9240	25.6	13.0	9260	31.5	13.6
Subsoiled, surface NH_4NO_3	6190	19.2	18.9	8930	25.2	12.4	8830	33.5	14.5
Subsoiled, surface urea	7470	18.5	18.4	8270	23.2	11.2	9210	34.7	13.3
Subsoiled, urea in track	7440	18.9	17.7	8920	26.9	12.2	9420	33.4	13.7
Subsoiled, urea + DCD in track	7400	18.1	18.3	8910	26.3	12.3	9250	32.3	14.1
Subsoiled urea + EDB in track	7100	17.2	19.0	8790	27.2	13.1	9340	33.7	13.8
$LSD_{0.10}$	767	NS	NS	683	1.49	0.82	NS	NS	NS
CV (%)	14.0	17.3	9.4	9.8	7.4	8.5	9.4	9.3	10.7

planting. Generally, within N source/application-method treatments, highest yields resulted from subsoiled treatments with urea as the N source, and lowest yields resulted from subsoiled treatments with ammonium nitrate as the N source. Within treatments with NH_4NO_3 as the N source, the trend for subsoiling to decrease yields is probably an artifact and not a true treatment effect.

In 1984, on the Norfolk soil, the only treatment effects on grain yield resulted from N source/application method treatments (Table 7). Grain yield and grain N concentration paralleled treatment effects on earleaf N concentration. The reduced N efficiency of surface-applied urea resulted in lowest yields.

In 1984, on the Dothan soil, time of N application/planting-tillage-method treatments affected grain yields ($P \leq 0.08$). Grain yields averaged 8650, 9090, and 9490 kg ha^{-1} for N at planting, N applied 5 weeks after planting to plots not subsoiled at planting, and N applied 5 weeks after planting to plots in-row subsoiled at planting, respectively.

Applying N 5 weeks after planting consistently resulted in higher yields than when N was applied at planting, as evidenced by single degree of freedom tests for treatments 1 through 8 vs. 9 through 24 (Table 8). Yields were 7360 vs. 6390; 8780 vs. 8490; and 9290 vs. 8650 kg ha^{-1} for N applied 5 weeks after planting vs. N applied at planting, for the Norfolk soil in 1983 and 1984, and the Dothan soil in 1984, respectively.

Since N applied 5 weeks after planting resulted in higher yields, single degree of freedom comparisons were used within these treatments to isolate effects of subsoiling treatments on grain yield (Table 9). In 1983, on the Norfolk soil, the lack of rainfall or irrigation or both, for the 47-day period following emergence resulted in substantial differences in grain yield from subsoiling timing and placement treatments. Average yields were 8390, 7690, 7020, and 5670 kg ha^{-1} for subsoiling in-row at planting (treatments 15, 16), in-row at planting plus interrow 5 weeks later (treatments 9, 10), interrow only, 5 weeks after planting (treatments 17, 18), and not subsoiling (treatments 23, 24), respectively. Single degree of freedom comparisons demonstrated no difference between subsoiling in-row at planting plus interrow 5 weeks later and either in-row at planting only, or interrow only 5 weeks after planting. Subsoiling in-row at planting plus interrow 5 weeks later (treatments 9, 10), in-row at planting only (treatments 15, 16), and interrow only, 5 weeks after planting (treatments 17, 18), increased yields over nonsubsoiled treatments (treatments 23, 24). Subsoiling in-row at planting increased yields over subsoiling interrow 5 weeks after planting (treatments 15, 16, vs. 17, 18).

Water was not limiting on either soil in 1984, and single degree of freedom comparisons demonstrated no differences in grain yield from subsoiling treatments on the Norfolk soil (Table 9). On the Dothan soil, the only difference among subsoiling treatments

Table 8. Results of preplanned comparisons by location and year for effect of time of N application on corn grain yield.

Soil and year	Grain yield: N at planting	Grain yield: N at 5 weeks	Significance of F test†	CV (%)
	kg ha^{-1}	kg ha^{-1}		
Norfolk, 1983	6390	7360	**	34.8
Norfolk, 1984	8490	8780	NS	7.7
Dothan, 1984	8650	9290	**	10.1

** Significant at the 0.01 probability level.
† Single degree of freedom tests of treatments 1–8 vs. 9–24.

Table 9. Results of preplanned comparisons by location and year for effect of subsoiling treatments on corn grain yields within treatments where N was applied 5 weeks after planting.

Comparison	Norfolk, 1983: Grain yield	Norfolk, 1983: Significance of F test	Norfolk, 1984: Grain yield	Norfolk, 1984: Significance of F test	Dothan, 1984: Grain yield	Dothan, 1984: Significance of F test
	kg ha^{-1}		kg ha^{-1}		kg ha^{-1}	
Subsoiled in-row (15, 16)†	8390		8280		9030	
vs.		**		NS		NS
Not subsoiled (23, 24)	5670		8340		8640	
Subsoiled in-row (15, 16)	8390		8280		9030	
vs.		***		NS		NS
Subsoiled interrow (17, 18)	7020		8500		8840	
Subsoiled interrow (17, 18)	7020		8500		8840	
vs.		*		NS		NS
Not subsoiled (23, 24)	5670		8340		8640	
Subsoiled in-row and interrow (9, 10)	7690		8630		9710	
vs.		**		NS		*
Not subsoiled (23, 24)	5670		8340		8640	
Subsoiled in-row and interrow (9, 10)	7690		8630		9710	
vs.		NS		NS		NS
Subsoiled in-row (15, 16)	8390		8280		9030	
Subsoiled in-row and interrow (9, 10)	7690		8630		9710	
vs.		NS		NS		NS
Subsoiled interrow (17, 18)	7020		8500		8840	
CV, whole plot (%)		34.8		7.7		10.1
CV, subplot (%)		14.0		9.8		9.4

*,**,*** Significant at 0.05, 0.01, and 0.10 probability levels, respectively.
† In-row subsoiling at planting; interrow subsoiled 5 weeks after planting.

resulted from the cumulative effect of in-row subsoiling at planting plus interrow 5 weeks after planting. The yield (9710 kg ha^{-1}) from this combination differed from the nonsubsoiled treatment (8640 kg ha^{-1}) (treatments 9, 10 vs. 23, 24).

CONCLUSIONS

In these tests, fertilizer N was utilized more effectively, resulting in increased yields when applied 5 weeks after planting rather than at planting. These results agree with those of Jung et al. (1972) and Russelle et al. (1983), who reported increased effectiveness of N from delayed applications. Placement of urea in the subsoil channel proved an effective method of applying fertilizer N. In one of three tests, nitrification of urea was retarded by either DCD or EDB; however, the use of these nitrification inhibitors did not result in increased grain yield. Early season plant growth was reduced when starter fertilizers were placed in the subsoil channel as opposed to 70 by 70-mm incorporated band, but starter placement did not affect grain yield. There was little benefit to subsoiling interrow 5 weeks after planting if corn was planted with in-row subsoiling. However, in 2 of 3 tests, subsoiling interrow 5 weeks after planting was as effective in increasing yields as in-row subsoiling at planting. This may be a practical alternate management tool, especially when used to apply sidedressed N, for growers in years when subsoiling at planting is not feasible due to soil conditions, equipment failure, or time considerations.

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